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Low Energy Routing for WSN's

Ravi Kishore Kodali[1] and Prof. Narasimha Sarma, NVS
National Institute of Technology, Warangal/Department of E.C.E., WARANGAL, India
Email: [1]ravikkodali@gmail.com

***Abstract*—The main tasks of a Wireless Sensor Network (WSN) are data collection from its nodes and communication of this data to the base station (BS). The protocols used for communication among the WSN nodes and between the WSN and the BS, must consider the resource constraints of nodes, battery energy, computational capabilities and memory. The WSN applications involve unattended operation of the network over an extended period of time. In order to extend the lifetime of a WSN, efficient routing protocols need to be adopted. The proposed low power routing protocol based on tree-based network structure reliably forwards the measured data towards the BS using TDMA. An energy consumption analysis of the WSN making use of this protocol is also carried out. It is found that the network is energy efficient with an average duty cycle of 0:7% for the WSN nodes. The OmNET++ simulation platform along with MiXiM framework is made use of.**

***Index Terms*— WSN, TDMA, Routing**

I. Introduction

Wireless Sensor Networks (WSNs) are being used in various diverse applications like environmental monitoring, structural health monitoring, fire detection, precision agriculture, etc. The WSN nodes carry out the measurements of various physical parameters using different sensor types and send the digitized values of these measurements to the BS making use of multi-hop connectivity. Generally, WSNs comprise of a large number of densely populated nodes and the deployment of the nodes can either be structured or be random. The WSN nodes should perform unattended. It is always not possible to replace the battery of each node considering the costs involved and terrain conditions and hazardous nature. The life time of the WSN application depends on its constituent nodes being alive. Hence, in order to extend the life of the WSN application, it is necessary to make use of the limited battery energy available with each node in efficient manner.

Among the constituent parts of a WSN node, sensors, microcontroller, memory, radio, and dc-dc power converter the radio module consumes the highest amount of power [1]. In order to reduce wastage of the battery energy, the radio needs to be turned on as and when it is required or the node requires to be put into sleep state. However, this transition from one state to another also involves energy drain. If a node is in its sleep state, recording of events and reporting them are going experience latencies. In order to extend the life of a WSN, its nodes need to spend some time in sleep state thereby conserving battery energy. The wakeup and sleep schedules associated with each node need to be exchange with the neighbouring nodes as synchronizing these schedules is required to facilitate multi-hop communication in a timely manner.

The radio control protocols are: random protocols (CSMA) scheduled protocols (TDMA). As the nodes are densely populated, causing congestion, leading to frequent retransmissions of data, thereby draining the battery energy in every node in the multi-hop connectivity. A TDMA based protocol eliminates collisions. They also minimize overhearing and idle listening problems. Further, these TDMA protocols permit the nodes be put into sleep state. In TDMA based protocols, a node advertises its wakeup state by broadcasting a beacon packet periodically. Those neighbouring nodes which listen to these beacon packets, respond by sending synchronization related data [1]. The node starts assigning a time slot of the time frame to each of its neighbours based on the order in which the responses are received from its neighbours. The objective of this paper is to develop a simulation model for a network layer protocol that focuses on low power consumption providing reliable communication. The proposed protocol employs a TDMA mechanism providing precise wakeup schedules for communication relying only on local synchronization to minimize the battery usage. The power is consumed mainly due to idle listening and overhearing. Idle listening can be avoided by turning off the radio when the nodes are idle and can periodically listen to the channel for any activity. By assigning time slots to each node of the network, the nodes can listen, transmit and receive in their own slots avoiding problems such as overhearing. It also provides clock drift compensation and avoids collisions due to overlapping of TDMA schedules.

II. Related Work

Due to its importance, data gathering in WSNs has attracted a lot of attention of the researchers in the recent years. The MAC protocols allow the radio to be turned off whenever possible to conserve limited battery energy. Two different approaches exist: Scheduled (TDMA) and contention-based (CSMA). In latter technique, the nodes turn off their radio for most of the time, only wakeup periodically to listen to the channel. If there is any activity, the node switches on its radio and listens for the incoming packet. But these protocols suffer from overhearing problem. In contrast to contention based approach, TDMA-based mechanisms establish a fixed schedule, where each node is assigned one or multiple slots for the data transfer. The nodes transfer data only during their slots avoiding collisions and overhearing problems. Pure TDMA protocols are hardly feasible for implementation as they require global time synchronization and are susceptible to topological changes. The scalability is a problem in TDMA based protocols. Hence most protocols use a combi

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nation of pure TDMA and contention-based. In [2], the time is divided into rounds and each round consists of three phases. It builds the tree, and then establishes a schedule for data transmission. In addition, a network wide time synchronization protocol is also used. The distributed MAC (DMAC) protocol [3] is optimized for data gathering. The protocol assumes a routing tree with the gateway node as its root. The active or wakeup periods of the nodes are assigned according to their level in the tree. CSMA is used to arbitrate among children in order to reduce collisions. The Flexible power scheduling (FPS) protocol [4] employs a TDMA approach, where every node maintains a separate schedule for each of its children. Although this schedule ensures that the parents and their children are contention free, still collisions may occur due to poor time synchronization. It relies on the other protocols for tree building and for global time synchronization.

III. Proposed Low Power Routing Protocol

In this paper, a Low Power Routing protocol is proposed. It is a TDMA based protocol and can be used in both flat and hierarchical topologies. The deployment of the nodes using this protocol can be either structured or random. A tree based topology modelling the WSN is created. In this topology the gateway node closest to the BS is assigned the role of the root node. The root node initiates the tree building process by broadcasting a beacon packet. All the neighbours of the root node which are one hop away respond to the root node with a connection request packet. Each of the neighbouring nodes is assigned a time slot by the root node in the order in which it received the corresponding connection request packet. All the neighbouring nodes, which have been assigned a time slot by the root node, are treated to be its children. In a similar manner, each of the root nodes children, further discover their respective child nodes. Each node, excluding leaf nodes, has a parent and its own children. The children are synchronized with their respective parents. Each of the child nodes of the given parent sends data in their respective time slots to the parent node. By following this approach, the data from a node is relayed to the gateway node, which in turn forwards it to the BS. The operation of the proposed protocol is divided into two phases:

1) Tree formation and its maintenance: It is a 3-way handshaking mechanism involving beacon packet, connectionrequest packet and the reply packet. The tree maintenance is accomplished by a periodic broadcast of beacon packets.

2) Data communication: In this phase, the measured data from a node is forwarded to its parent and relayed further to the root node or gateway node.

A. Tree formation and its maintenance

The tree formation ensures that there exists at least one communication path between each node and the gateway node. The tree maintenance enforces the connectivity among the nodes in a communication path, from a node to the root node. In case of any connection failure, an alternate parent is chosen from its routing table entries. Each node maintains its own routing table with entries which correspond to the addresses of those nodes from which it received beacon packets. The tree formation is initiated by the root node by broadcasting a beacon packet. All the nodes in the vicinity listen to this beacon packet and place a request for connection. The beacon packet (B) has the following fields: the senders address, its number of child nodes, the number of hops away from the child node, and a random seed value. This seed value is used to initialize the timer used during the synchronization of wakeup-sleep schedules. Upon receiving a beacon packet, a node stores this information in its routing table. All such information is collected from various different beacon messages and is stored. The addresses of various parents are sorted based on the number of hops and the number of children.

A parent node sends a beacon message, B, for every beacon interval. In response to this B, a child node which hears this beacon places a connection request, C. This connection request, C, is acknowledged by the parent node through a reply message, H confirming connectivity between the parent node and the child node.

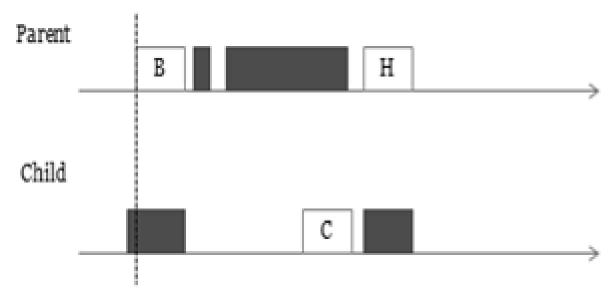

Figure 1: Connection Setup

If the child node has some data to be forwarded it waits for its assigned time slot of its parents TDMA schedule. By initializing the timer for this purpose, the node can go to sleep state. The connection establishment is a three-way handshake mechanism, given in Figure 1 All the parent nodes maintain their TDMA schedules for their respective child nodes. All the child nodes maintain routing tables representing their respective parents. Some nodes can act both as a parent and child. Once the tree is formed the connectivity is ensured by beacon packets received by the

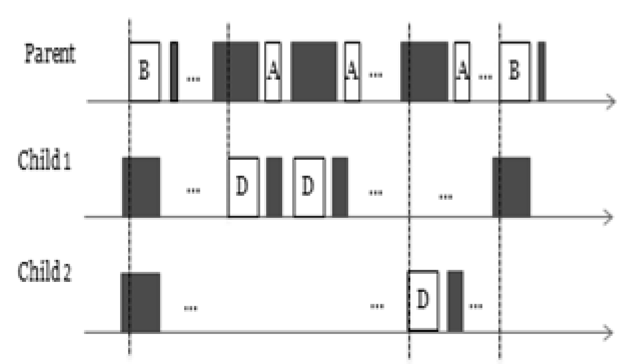

Figure 2: Data Communication between a parent and two of its children

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child node. If there are three consecutive data transfer failures then the connection between a node and its parent is treated as being broken. This kind of link
failures ought to be handled in order to ensure reliable data transmission. The proposed protocol includes a mechanism to recover from such link failures by looking into the routing table for alternate parent. If the node does not have any alternate parents to choose from, then it gets into bootstrap mode. In this mode, the node goes to sleep state for a while, and then the node starts afresh by listening for beacons.

B. Data Communication

After the proposed routing protocol has established a communication path between a node and the root node, the data transfer using this connectivity can be carried out.This connectivity involves multi-hop communication. A data queue is maintained by each node in order to store the incoming packets from the application layer. The child nodes can send their data to their respective parents only during the time slots assigned to them. The parent nodes send an acknowledgement, A, upon receiving the data packet, D, from its child nodes. It is possible to send more than one data packet, D, in its single time slot. However, an acknowledgement, A, from its parent is needed for every data packet, D. If there is no acknowledgement for a data packet sent by a child node, the child node stops further transfer of data packets for that time slot. The same is presented in Figure 2.

A consecutive data transfer failure between a child and its parent is said to occur if the beacon packet not being received for three consecutive beacon intervals by the child node or a data packet is not acknowledged even after three attempts in three successive time slots of the child node. When this link failure occurs, child nodes attempt to choose another parent. All the data packets received from the child nodes are also stored in the data queue along with the measured data packets. The size of the data queue is limited due to storage constraints.

IV. Simulation And Performance Analysis

The OMNeT++, [5] a discrete event simulator based on C++ is used as simulation platform. The simulation model is developed using MiXiM [6] framework. The model is evaluated against the following performance criteria: duty cycle, lifetime of a node and reliability of data transfer.

A. Simulation Model

For the purpose of developing a WSN model, it is assumed that about 50 numbers of Micaz [7] nodes are deployed over a grid based structure of 1000m X 1000m area. A model for the Micaz mote is developed using MiXiM framework. This mote module supports the standard protocol suite. The mote module also provides the battery and the radio modules that are needed while monitoring the power consumption during communication. Every node has a power source of 3.3 volt battery with an initial capacity of 2000 mAH. The current drawn for sleep mode, receiving and sending, and the radio transition delays are shown in Table I [8].

B. Protocol Parameters

The communication range values of the nodes are maintained by the ConnectionManager module of the MiXiM framework. Among the 50 sensor nodes, a node, the node 26, is chosen as the gateway node, or the root node of the tree structure and this root node is responsible for initializing the tree building process. Table II shows the important parameters and their assigned values for the purpose of simulation.

C. *Performance Analysis*

The performance of the proposed protocol is compared with the WiseRoute protocol [5], a built in convergecast routing protocol. The WiseRoute is a CSMA based protocol. Duty cycle and energy consumption: The nodes energy consumption is a function of its duty cycle. Based on the duty cycle of a node, the total wakeup state duration is computed, while carrying out simulation study of the model. Based on the computed wakeup state duration, the power consumption share of the radio can be arrived at. It is observed that the overall average duty cycle of all the nodes is about 0.7%. While carrying out simulation of the WSN model, the duty cycle of every node is recorded and the same is shown in the Figure 3. From this plot, it can be observed that the root node, node-26, has the highest duty cycle of 1.46%. This is because it has to process the data of the entire network and so it stays awake for a longer time when compared to the remaining nodes. Few nodes, like leaf nodes or the nodes in sparsely populated neighbourhoods, with higher duty cycles around 1% are those that spent more time while establishing connectivity to their respective parents.

Table I. Current Consumption And Radio Switching Times Of The Node [8]

Battery Parameter	*Value*
Transmit current	17.4 mA
Receive current	18.8 mA
Sleep current	0.021 μA
Receive to Transmit time	0.000192 s
Transmit to Receive time	0.000192 s
Sleep to Receive time	0.001792 s

Table II. Simulation Parameters

Simulation Parameter	Value
Topology Size	1000 X 1000 m2
Channel Type	Wireless channel
Antenna Type	Omnidirectional
Number of Nodes	50
Beacon interval	30 s
Data sampling interval	120 s
Potential beacon interval	15 min
Clock skew	100 ppm
Queue length	25
Slot time	50 ms
Node battery capacity	2000mAh, 3.3 V

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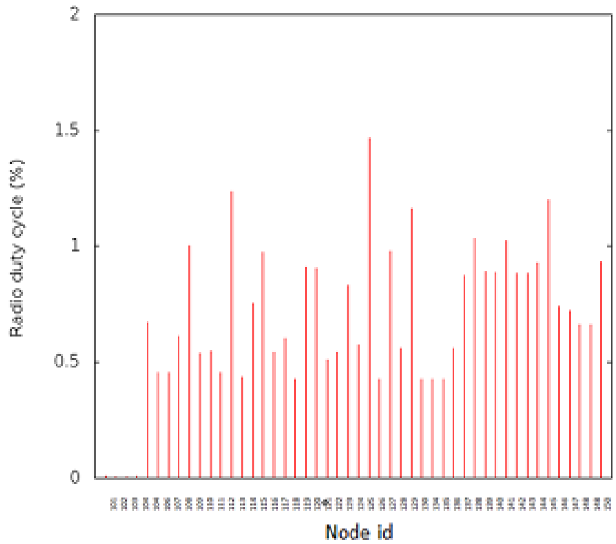

Figure 3: Average radio duty cycle of the nodes of the network

While performing simulation of the WSN under similar conditions, the battery residual capacity of every node is recorded separately for both the low power routing protocol and the WiseRoute protocol and the plots are shown in Figure 4. For the purpose of comparison, the nodes battery capacity is limited to 1mAH. It can be observed that the node life time of the convergecast WiseRoute protocol is very less when compared to that of the proposed protocol. It may be concluded that the contention-based protocols are unsuitable for WSN applications despite being scalable Data Reliability: It is assumed that every node generates up to 50 data packets for the purpose of simulation study. While performing simulation, the total number of data packets received by the root node from each of the remaining nodes of the WSN is recorded as the time elapses and the same is plotted in the Figure 5. The total number of data packets generated in the whole simulation is 2,450. All the data packets sent by the nodes are received by the root node. Each data packet is generated at every 120s. The total time taken for the 2,450 data packets to be generated is 7,500s. The plot shows that the root node received all the generated

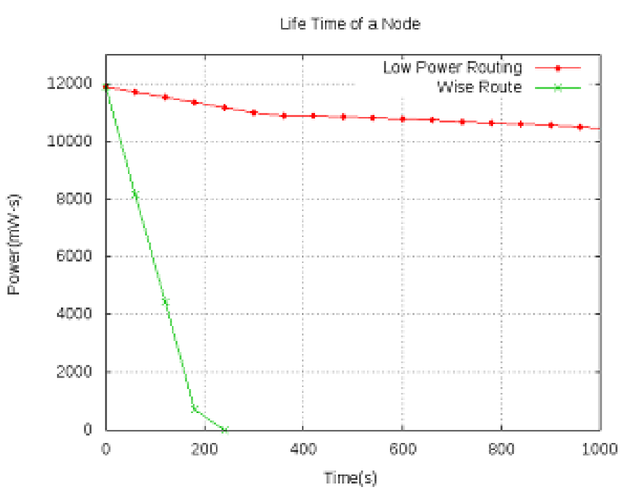

Figure 4: Comparison of node life time of the proposed protocol WiseRoute

data around 7,500s. This also shows that there are no latency issues associated with data delivery in this simulation study.

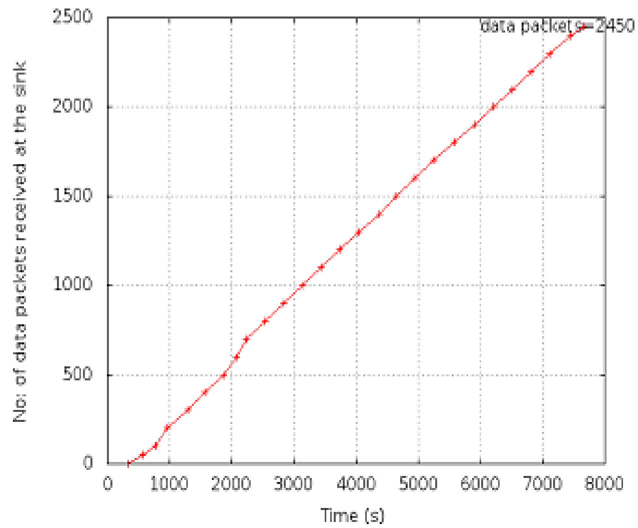

Figure 5: No. of Data packets received at the root vs. simulation time

V. Conclusions

This paper proposes a low power routing protocol for small to medium scale WSN applications, where periodic data collection and reliable delivery are required. A simulation model for the protocol is created and simulation studies are carried out. It is observed that the overall average duty cycle of all the nodes is around 0.7 percent. This tree based topology is a fault tolerant WSN. The protocol can also be used for disseminating node specific configuration parameters and control information from the BS through the root node.

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